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Application of Geophysical Survey for Subsurface Investigation of an Erected Multistory Building in Southwestern Nigeria

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Abstract

Globally, engineering structures are constructed with the expectation to stand a test of time. However, the rate at which buildings are collapsed after few years of construction in Nigeria has been of great concern. An integrated geophysical survey was carried out around a storey building in southwestern Nigeria, to explore the sub-surface characteristics which may have caused cracks in this building and to address its safety and stability conditions. The geophysical methods used for the investigation were the Very Low Frequency Electromagnetic (VLF-EM) and Electrical Resistivity methods involving Schlumberger and 2-D dipole-dipole arrays. The VLF-EM measurements were taken at an interval of 5 m along eight traverses. Twenty vertical electrical sounding (VES) stations were occupied from the results of VLF-EM method. The 2-D dipole-dipole array was employed for the subsurface imaging. The acquired data were processed and interpreted to understand the shallow structural setting in the area. Evaluation and interpretation of processed data led to the delineation of vertical and sub-vertical linear features such as faults, fracture zones, depressions and geologic contacts. The results revealed four distinct subsurface geo-electric layers which comprised of topsoil, weathered layer (clay type), fractured layer and fresh bedrock (granite gneiss). The undulating nature of the bedrock topography was shown with depth to bedrock between 3.5 and 12.6 m. The weathered layer beneath the topsoil upon which the foundation was erected displayed relatively low resistivity values ranging from 42 – 151 Ohm-m, typical of geotechnical incompetent formation containing clay. These geologic features and the clayey formations must have been responsible for the foundation instability leading to cracks observed on the building.

Keywords: Very low frequency electromagnetic, Electrical resistivity, Sub-surface characteristics, Foundation instability, Engineering structures.

Introduction

The high rate of failures of engineering structures such as roads, buildings, dams and bridges have been a major concern to the various tiers of government, engineering geologists, architects, researchers and the communities at large as it happens almost every day in Nigeria. The availability of soil makes it an indispensable and important materials for construction

on which engineering structures are placed except when erected on rocks (Johnson and DeGraff, 1988).

Fig. 1.Crack from first to the ground floor of the storey building.

A basic understanding of certain physical characteristics of soil aid engineering geologists in their evaluation of soils and their uses because a balanced interaction of the soil and structure must be ensured as this form the basis of a stable foundation (Oluwafemi, 2012). Poor soil stability has posed problems for nearby engineered works because of the sensitivity of some soils to moisture gain or loss. Clayey soils expand when saturated and shrink in volume when there is loss of water in them. As the soil goes through wet and dry periods, the soil expands and shrinks. Structures built on top of the clay soil rise and fall with the soil which result to “differential” foundation movement which leads to cracking and distress. Foundation cracks on buildings occur as a result of differential movement on the building. The size, shape, pattern and location of foundation cracks on a building, when correlated with other site and construction conditions, help to distinguish among probable causes of foundation based failures (Tim, 2002). Settlement could be as a result of weakness of the soil beneath the foundation or beneath the building’s column supports, unstable soil, structures above concealed cavities or organic material, expansive soils, lifting by growth of ice, shock, vibration or regional subsidence, hydration of anhydrite in rocks on which they are founded, foundation located on landslides. The degree of damage caused by settlement is to some extent dependent on the sequence and time of construction operations (Tomlingson and Boorman, 1999; Sands, 2002). Recently a valid alternative to direct investigation methods, in order to study the stability of galleries, foundation, etc., is the use of the geophysical surveys. Although in many cases in the assessment and monitoring phases, direct methods, such as drillings are used to establish the stability, yet such methods may damage the structure and may often be very costly and provide information that cannot always be extrapolated to large areas (Leucci and De Giorgi, 2005). Meanwhile, geophysical techniques are generally quick, inexpensive and generally non-destructive to provide information about the subsurface properties, depth to bedrock, location and distribution of conductive fluids, location and orientation of fractures and faults with accuracy in the shallow subsurface (Reynolds, 1997). The objective of this study is to carry out the post-foundation evaluation of the Faculty of Education building, Adekunle Ajasin University, Akungba Akoko using an integrated geophysical method. The purpose is to explore the sub-surface characteristics which may have caused cracks in this multistory building and to address its safety and stability conditions.

Location and Geology of the Study Area

The study area is the Faculty of Education building in Adekunle Ajasin University, Akungba-Akoko, Nigeria which consists of offices (Fig. 1). It is a storey building donated by Access Bank (formerly Intercontinental Bank). It lies between latitudes 7° 27' 21.6”N and 7° 29' 14.46”N and longitudes 5° 43' 33.84” E and 5° 44' 53.34” E. The study area lies within the Precambrian Basement Complex rocks of southwestern Nigeria, underlain by migmatite- gneiss-

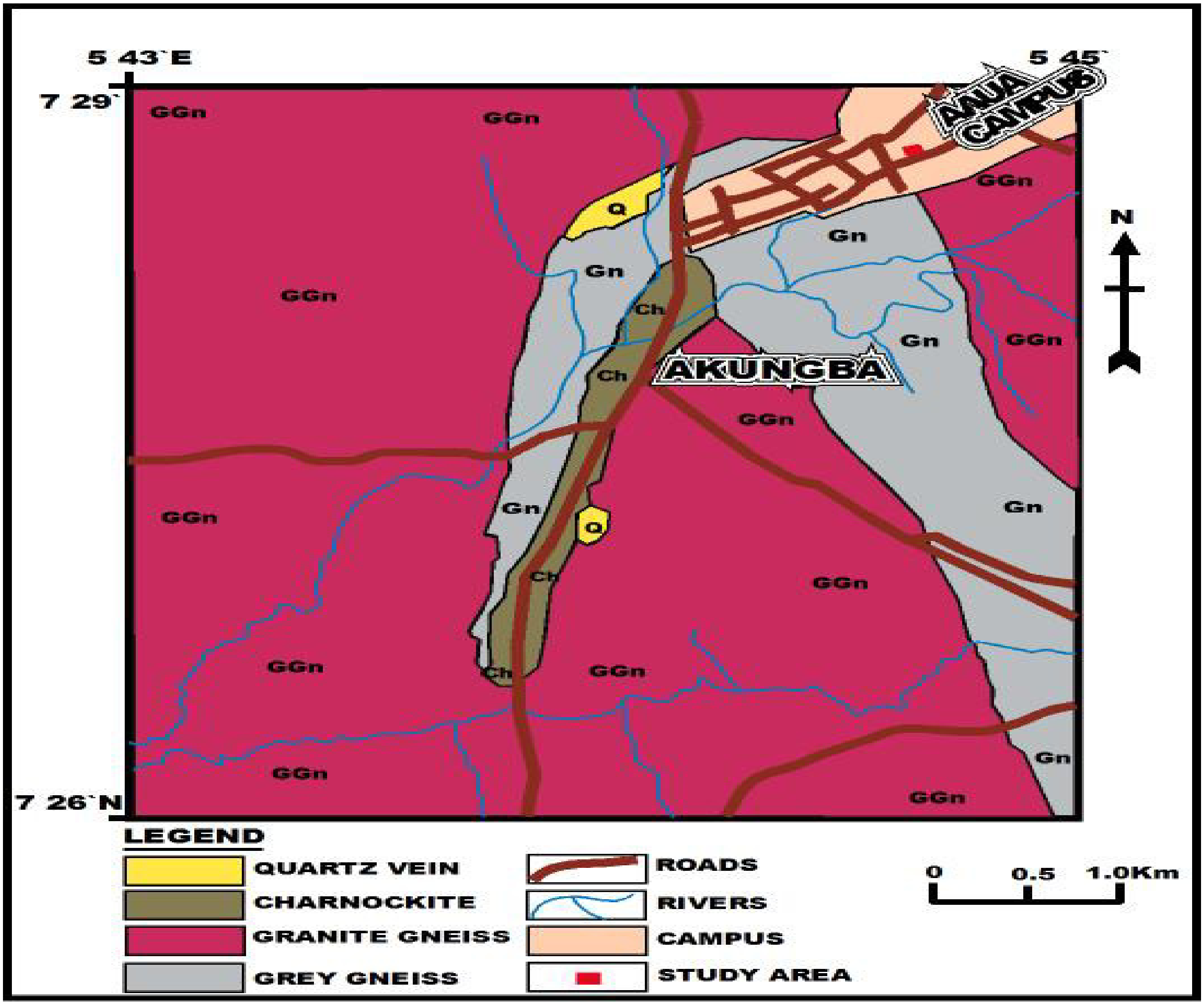

Fig. 2. Geological Map of Akungba Akoko showing the study area (Extracted from Geological Map of Ondo State).

quartzite complex with the granite gneiss and grey gneiss being the major units (Fig. 2) while the minor units include mafic, granodiorite, pegmatite, garnet-sillimanite gneiss and quartzite (Rahaman, 1988). Based on field observations, the identified lithological units comprise of migmatite gneiss, charnokitic rocks and fine to medium grained biotite granite. Migmatite gneiss are dominant in the study area which are extensively weathered and fractured, with prominent direction of foliation lying between 176^0 and 184^0 with easterly dips of 44^0 and 76^0 (Oluwafemi and Ogunribido, 2014). They occur as ridges and hills which contain quartz veins, dykes, quartzo-feldspathic intrusion and pegmatitic veins usually very extensive. The granite forms the basement lithology in some other parts of the study area. These rocks are generally trending in N-S direction typical of the basement complex rocks. Structural features such as faults, joints, xenoliths, folds, dykes etc. characterize the

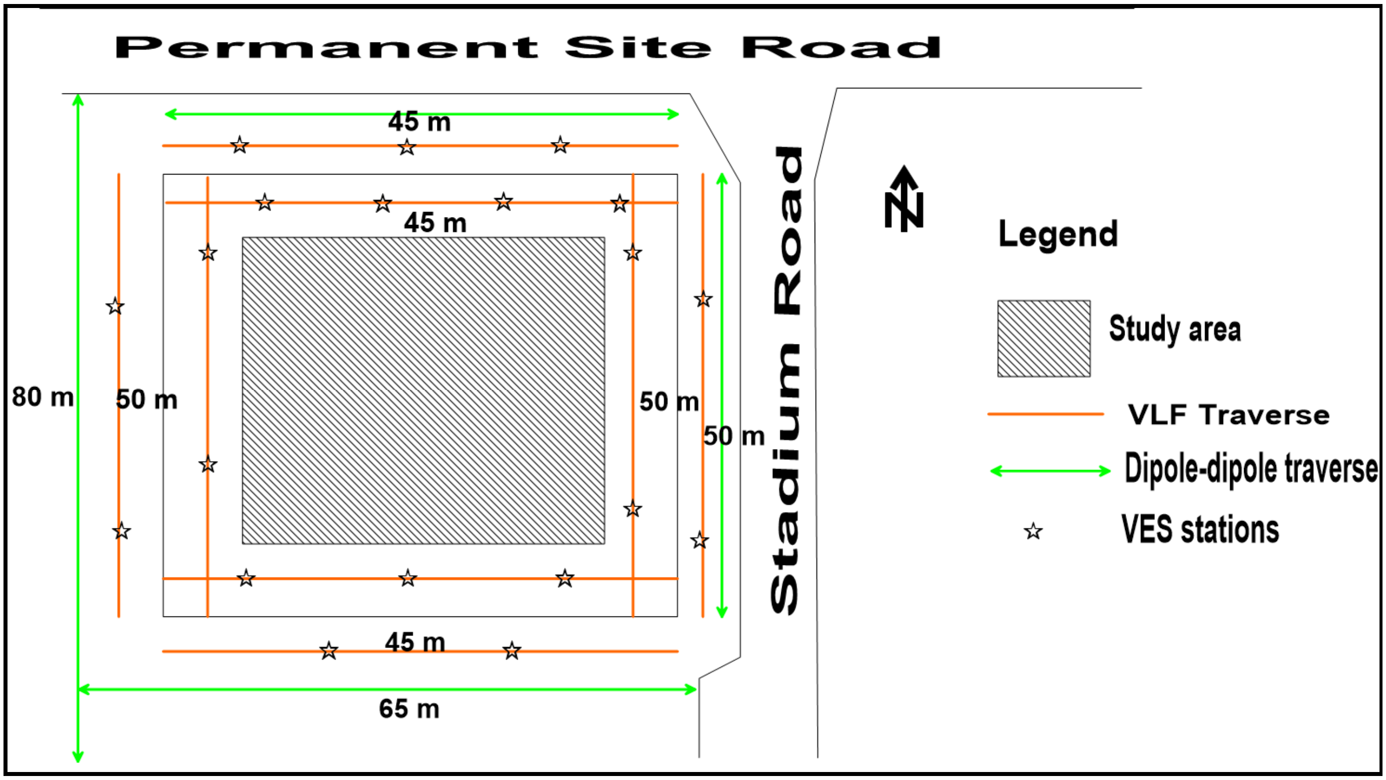

Fig. 3. Geophysical field layout map of the study area.

rocks. The older granite of the study area is grey with a speckled appearance caused by the darker crystals.

Materials and Methods

The geologic mapping of the area involves studying of rock outcrops and their distribution on the environment of the study area, road networks and major features so as to produce a sketch map of the study area. Eight VLF-EM traverses and four dipole-dipole traverses were established in an approximately NW-SE direction within the survey area (Fig. 3). The profiling technique was employed for the VLF-EM using a station separation of 5 m along the established traverses and perpendicular to the transmitter signal direction.

The VLF-EM and the electrical resistivity geophysical methods were used in this survey. The electrical resistivity method utilized the Vertical Electrical Sounding (VES) and the dipole – dipole profiling techniques to image the subsurface. The EM measurement engaged the ABEM WADI equipment, which measures the in-phase (Real) and quadrature (Imaginary) components of the induced vertical magnetic field as a percentage of the horizontal primary field along the eight profiles. Measurements were taken at 5 m intervals along each of the traverses in the West-East direction. The very low frequency electromagnetic data were processed by downloading the raw real and filtered real components from the Abem Wadi VLF-EM equipment. The data are presented as profiles by plotting the raw real and filtered real components against distance (Figs. 4 and 5). The VLF-EM data were also interpreted and inverted into a 2-D section using the Karous-Hjelt and Fraser filtering (Pirttijarvi, 2004).

Twenty Schlumberger depth Soundings were conducted at selected locations based on the results obtained from the VLF surveys along the traverses (Fig. 3), to investigate the vertical changes in the resistivity distribution. The VES data interpretation involved the convectional preliminary partial curve

matching (Patra and Nath, 1998) The model derived from the manual interpretation was iteratively adjusted, using Win RESIST version 1.0 (Vander Velper, 2004) software, to get a better fit in each case. The 2-D subsurface imaging was carried out with the dipole – dipole profiling. Measurements were made at electrode spacing of a = 5 m and expansion factor of n, varying from 1 – 5 depending on the length of each profile. A few electrodes were skipped during the data acquisition because of the presence of features like concrete slabs and road tars but it was ensured that the ground was having a firm contact with the electrodes insertion. The dipole – dipole data were inverted into 2-D resistivity structures, using the DIPRO for windows (2000) software.

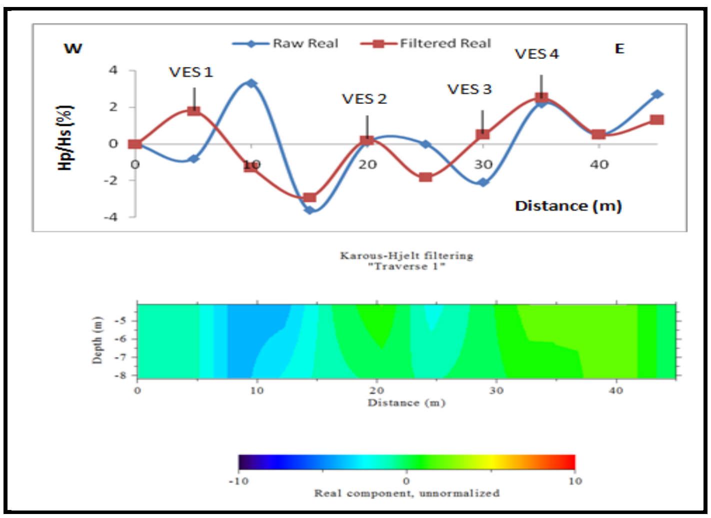

Fig. 4a. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 1.

Results and Discussion

VLF – EM Profiles and Karous-Hjelt Pseudosections

The double plots of the raw real and filtered real components enable qualitative identification of the top of linear features. The VLF-EM profile identified peak positive filtered real values suspected to be fracture zones at distances 5 m, 20 m and 30 m – 35 m along traverse 1, 5 m, 25 m and 40 m along traverse 2, 15 m – 25 m along traverse 3 and 10 – 25 m along traverse 4 (Fig. 4).

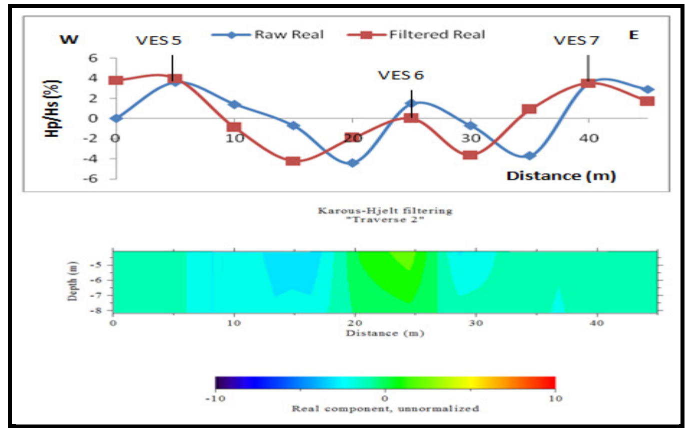

Fig. 4b. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 2.

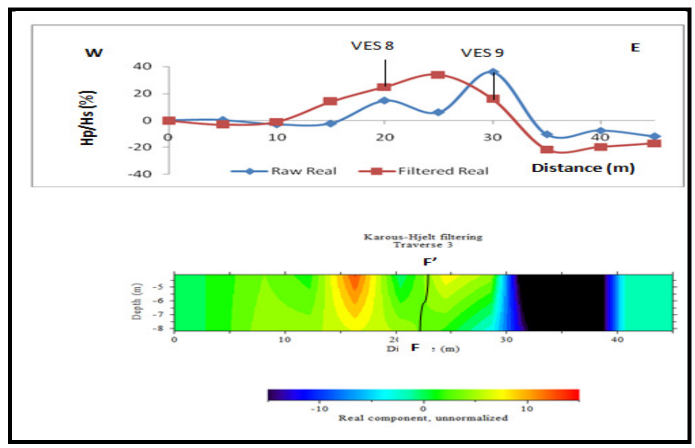

Fig. 4c. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 3.

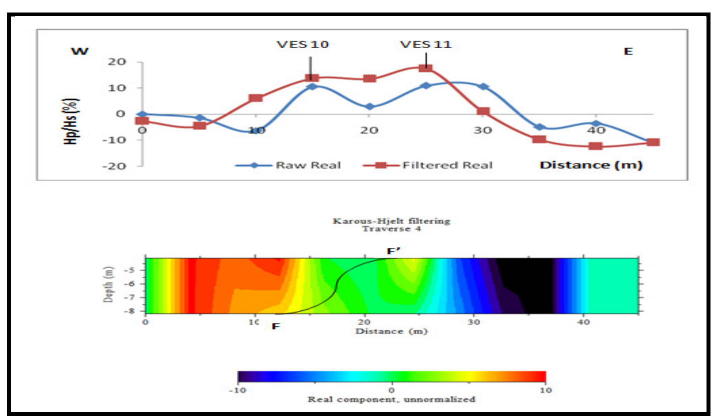

Fig. 4d. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 4.

The Karous-Hjelt pseudo-section (K-H section) of the profile which is a measure of conductivity of the subsurface as a function of depth is shown in Figs. 4 and 5. This conductivity is shown as colour codes with response increasing from left to right (i.e. from negative to positive). The 2-D model section of the EM filtered real profiles reveal points showing conductive zones. Major conductive features of varying degree of conductivity trending in different directions were delineated on the sections. The observations of the conductive features on these profiles agree with the conductive zones delineated by the Karous and Hjelt section at distances 17 – 24 m and 29 – 43 m along traverse 1 (Fig. 4a), 19 – 27 m along traverse 2 (Fig. 4b), 3 m – 28 m along traverse 3 (Fig. 4c) and 2 m – 25 m along traverse 4 (Fig. 4d). The conductive zone between 13 to 20 m along traverse 3 (Fig. 4c) and between 3 to 15 m along traverse 4 (Fig. 4d) are typical of linear features (fractures, F-F') which are characteristic zones of weakness responsible for the rock instability with attendance cracks observed on the building. The same process of qualitative interpretation was adopted for the remaining profiles and Karous-Hjelt pseudo-sections (Figs. 5a-5d).

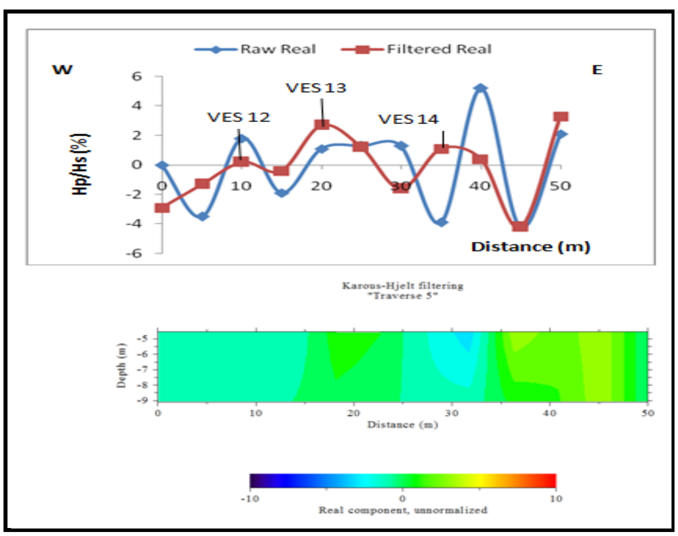

Fig. 5a. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 5.

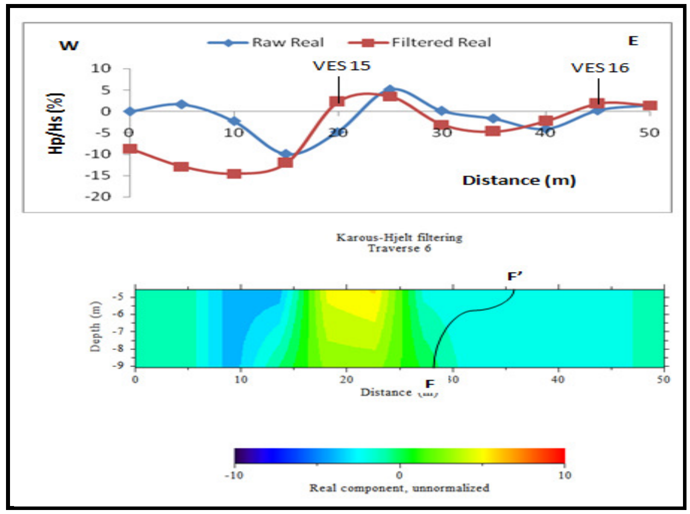

Fig. 5b. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 6.

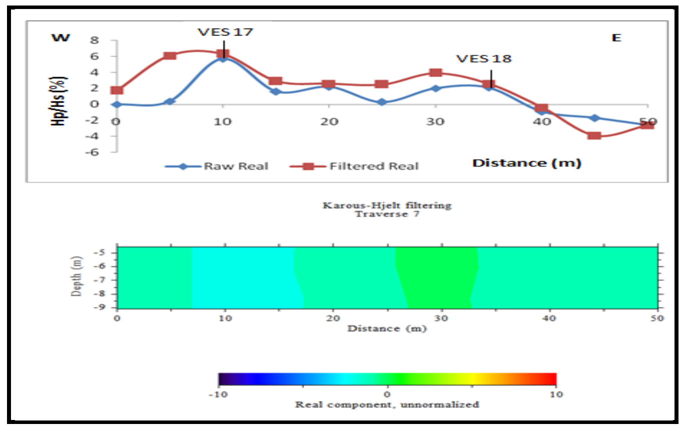

Fig. 5c. VLF-EM Profiles andKarous and Hjelt pseudosections along Traverse 7.

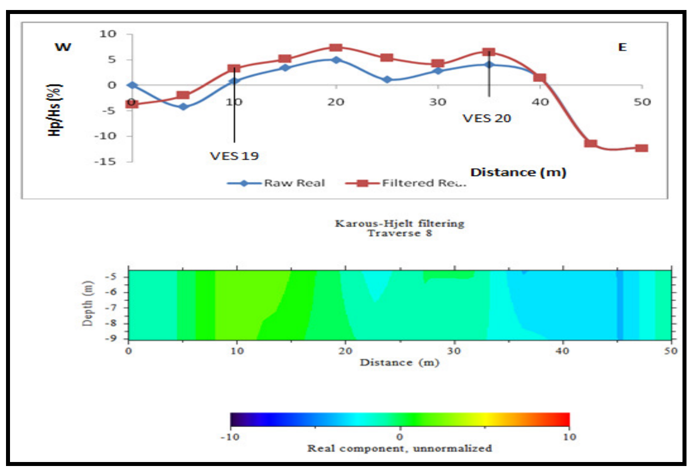

Fig. 5d. VLF-EM Profiles and Karous and Hjelt pseudosections along Traverse 8.

Table 1. Summary of the VES interpretation results of the study area.

VES Station	Layer resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve type
1	228.3	1.9	1.9	Topsoil	H
	42.3	4.0	5.9	Weathered layer (clay)	
	2825.7	-	-	Fresh Basement	
2	221.0	2.2	2.2	Topsoil	H
	65.2	4.6	6.8	Weathered layer (clay)	
	2437.0	-	-	Fresh Basement	
3	268.1	3.7	3.7	Topsoil	H
	88.5	3.4	7.1	Weathered layer (clay)	
	701.3	-	-	Fractured Basement (clayey sand)	
4	181.7	2.7	2.7	Topsoil	H
	97.2	3.9	6.6	Weathered layer (clay)	
	832.9	-	-	Fractured Basement (clayey sand)	
5	301.7	1.8	1.8	Topsoil	H
	76.4	4.0	5.7	Weathered layer (clay)	
	1873.0	-	-	Fresh Basement	
6	288.9	3.1	3.1	Topsoil	H
	71.3	9.5	12.6	Weathered layer (clay)	
	2577.3	-	-	Fresh Basement	
7	239.0	1.6	1.6	Topsoil	H
	151.2	4.7	6.4	Weathered layer (clay)	
	1046.7	-	-	Fresh Basement	
8	362.0	1.6	1.6	Topsoil	HA
	94.4	3.7	5.3	Weathered layer (clay)	
	679.1	5.8	11.1	Fractured Basement (clayey sand)	
	2131.0	-	-	Fresh Basement	
9	233.9	1.5	1.5	Topsoil	HA
	52.5	2.4	3.9	Weathered layer (clay)	
	830.5	4.4	8.3	Fractured Basement (clayey sand)	
	3557.4	-	-	Fresh Basement	
10	238.8	1.7	1.7	Topsoil	HA
	57.8	2.6	4.3	Weathered layer (clay)	
	721.2	4.2	8.5	Fractured Basement (clayey sand)	
	3453.9	-	-	Fresh Basement	
11	244.8	1.4	1.4	Topsoil	HA
	74.5	3.4	4.8	Weathered layer (clay)	
	584.5	4.8	9.6	Fractured Basement (clayey sand)	
	2899.6	-	-	Fresh Basement	
12	234.6	0.7	0.7	Topsoil	HA
	77.3	2.1	2.8	Weathered layer (clay)	
	573.6	4.2	7.0	Fractured Basement (clayey sand)	
	1728.3	-	-	Fresh Basement	
13	363.6	0.7	0.7	Topsoil	HA
	75.3	2.2	2.8	Weathered layer (clay)	
	599.5	3.7	6.6	Fractured Basement (clayey sand)	
	2319.8	-	-	Fresh Basement	
14	247.6	1.5	1.5	Topsoil	HA
	94.1	4.1	5.6	Weathered layer (clay)	
	648.8	6.4	12.0	Fractured Basement (clayey sand)	

	1969.0	-	-	Fresh Basement	
15	161.0	1.2	1.2	Topsoil	HA
	68.7	2.9	4.2	Weathered layer (clay)	
	751.1	5.4	9.6	Fractured Basement (clayey sand)	
	2720.0	-	-	Fresh Basement	
16	218.5	0.7	0.7	Topsoil	HA
	58.5	1.7	2.4	Weathered layer (clay)	
	893.7	3.6	6.1	Fractured Basement (clayey sand)	
	2439.5	-	-	Fresh Basement	
17	210.3	0.8	0.8	Topsoil	HA
	59.2	1.8	2.6	Weathered layer (clay)	
	873.1	3.9	6.4	Fractured Basement (clayey sand)	
	3144.9	-	-	Fresh Basement	
18	242.7	1.1	1.1	Topsoil	H
	81.3	3.3	4.4	Weathered layer (clay)	
	1516.4	-	-	Fresh Basement	
19	215.9	1.2	1.2	Topsoil	H
	64.8	2.8	4.0	Weathered layer (clay)	
	3006.6	-	-	Fresh Basement	
20	232.3	1.1	1.1	Topsoil	H
	55.5	2.5	3.5	Weathered layer (clay)	
	2304.6	-	-	Fresh Basement	

The identified conductive zones (anomalies in yellow – reddish colour bands) are suspected to be fault/fracture zones and sheared zones within the bedrock. The fractured zones are considered as weak zones liable to cause foundation failure and total collapse of structures erected on it because it is characterized by low bearing capacity, and are consequently geotechnically incompetent to support the weight of heavy civil engineering structures. Based on this interpretation, the points of interest marked as conductive zones (suspected fracture zones) were the points that were further investigated using the Vertical Electrical Resistivity Sounding (VES) namely VES 1 to VES 20.

Resistivity Sounding Curves and Geoelectric Sections

The resistivity sounding curves identified in the study area are H and HA type which constitute 50% each. The geoelectric sections along the traverses show four geologic subsurface layers comprising the top soil, weathered layer (clay), fractured basement and fresh basement rock (Figs. 6a - 6d). The topsoil varies in composition from sandy clay to clayey sand with resistivity values ranging from 161 – 364 ohm-m and the thickness vary from 0.7 m – 3.7 m. The topsoils are generally thin with the predominant thickness generally less than 2 m except beneath VES stations 2, 3, 4 and 6 (Table 1 and Figs. 6a-6d). The resistivities of the weathered layer are generally less than 100 ohm-m except beneath VES station7 with resistivity value of 151 ohm-m. The thickness varies from 1.7 m to 9.5 m, which constitute the water bearing layer. Adequate measures should be taken since part of the study area is consisting of clay and clayey sands at shallow depths to avoid foundation failure or sudden collapse of engineering structures (Oluwafemi and Ogunribido, 2014). 50% of the VES curves indicate subsurface partly weathered/fractured basement classified as fractured unconfined (with HA type curve) basement column. The layer resistivity values vary from 574 – 894 ohm-m while its thickness ranges from 6.1 – 12.0 m. The fresh basement resistivity values range from 1047 ohm-m to 3557 ohm-m which

is an evidence of fresh basement bedrock. The depth to the bedrock varies from 3.5 to 12.6 m (Table 1 and Figs. 6a – 6d).

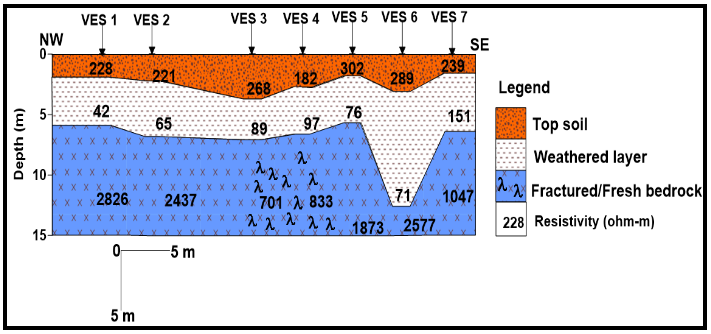

Fig. 6a. NW-SE 2-D Geoelectric Section along traverses 1 and 2.

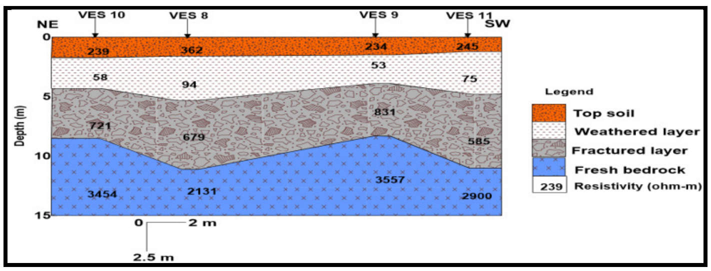

Fig. 6b. NE-SW 2-D Geoelectric Section along traverses 3 and 4.

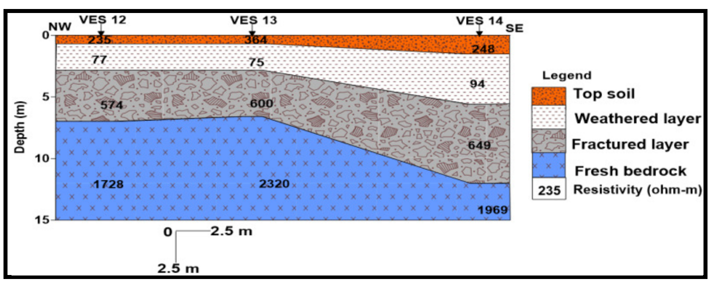

Fig. 6c. NW-SE 2-D Geoelectric Section along traverse 5.

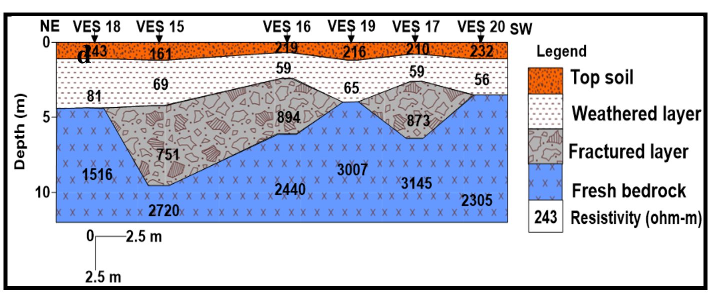

Fig. 6d. NE-SW 2D Geoelectric Section along traverses 6, 7 and 8.

It was observed that the subsurface at depth of 1 m to 3 m within which the building is sited is characterized of mainly clayey materials with low resistivity values ranging from 42 ohm-m to 151 ohm-m and thickness varying from 1.7 m to 9.5 m corresponding to area of greatest water saturation in the area could be attributed to the development of cracks in the building. The electrical resistivity of a formation is directly related to the nature, quantity, quality and distribution of the formation water (Adewumi and Olorunfemi, 2005). The structural failure related cracks on the building is also due to the presence of near surface bedrock depressions, occupied by low resistivity weathered materials typical of water-saturated clays which is unsuitable construction materials.

Dipole-dipole Pseudo sections

The 2-D pseudosection was produced from the dipole-dipole data taken along the eight traverses indicating the lateral variation of the subsurface lithology with depth (Figs. 7-10). This gives similar information as the geoelectric sections. It delineated topsoil, weathered layer, fractured layer and the fresh bedrock. The highly resistive parts are seen at the lower part of the sections which is the fresh bedrock while the green and blue coloured parts are the weathered/fractured part of the sections. The weathered layer beneath the topsoil upon which the foundation was erected displayed relatively low resistivity values of > 150 ohm-m and 42 – 151 ohm-m from both 2-D resistivity structures and the geoelectric sections respectively. Estimated weathered layer thickness of 1.7 – 9.5 m from the geoelectric interpretation results corroborates estimated depth > 3 – 9 m from the 2-D resistivity structures

Traverses 1and 2

This profile (Fig. 7) shows four distinct geologic layers. The first layer is a relatively resistive layer having resistivity values in the range of 102 – 498 ohm-m which can be observed across the section at depths between 0 – 3 m. This area indicates the

presence of clay/sandy clay/clayey sand. Beneath this layer is a very low resistivity layer of less than 100 ohm-m as can be observed across the traverse at depths between 3 – 9 m. This layer indicates the presence of high water retaining material (clay) due to its very low resistivity value range. The third layer with resistivity values in the range of 150 – 500 ohm-m, this layer indicates the presence of a weathered/fractured basement material at depths between 9 – 15m, stretches across the section. However, a medium of more resistive layer having resistivity values in the range of 532 – 3387 ohm-m, indicating the presence of a fractured/fresh basement rock.

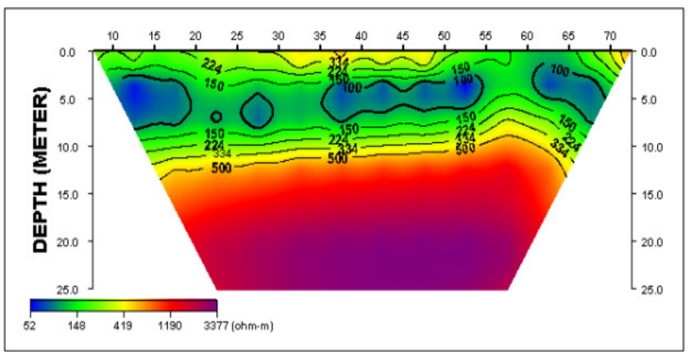

Fig. 7. 2-D subsurface resistivity image along traverses 1 and 2.

Traverses 3 and 4

The profile (Fig. 8) shows relatively thick layer topsoil (about 5 m thick) with the resistivity ranging from 104 – 649 ohm-m composed of clay/sandy clay/clayey sand/laterite. Below this unit is a conductive layer of about 5 m thick forming closures and have resistivity values less than 100 ohm-m. Below this conductive layer is another layer of resistive material with resistivity in the range of 150 – 692 ohm-m which indicates the presence of a weathered/fractured basement material at depths between 10 – 16 m, stretches across the section. The fresh basement rock is having resistivity values ranging from 731 – 3390 ohm-m with depths in the range of 15 m to 25 m.

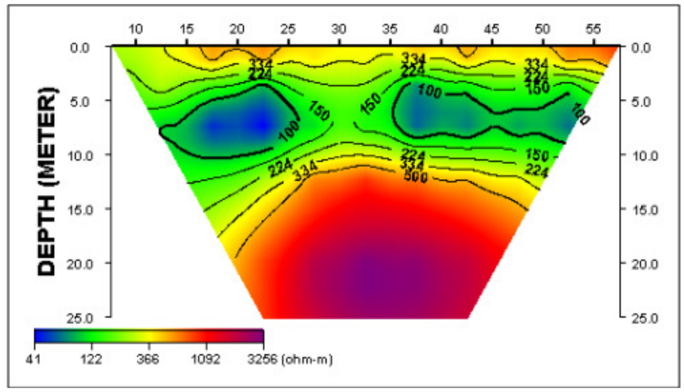

Fig. 8. 2-D subsurface resistivity image along traverses 3 and 4.

Traverse 5

This traverse (Fig. 9) clearly shows that the topsoil is composed of clayey sand/laterite with resistivity values varying from 332 – 590 ohm-m. The weathered layer ranges in composition from clay and sandy clay with resistivity values that vary between 20 and 217 ohm-m and depth of between 2 – 10 m. The fractured layer with resistivity values in the range of 351 – 903 ohm-m stretches across the section. It ranges in depth of between 10 – 17 m. This layer indicates the presence of a weathered/fractured basement material. However, a medium of very high resistivity values in the range of 903 – 1619 ohm-m as can be observed at depths of 17 m to 25 m indicating the presence of a fresh basement rock.

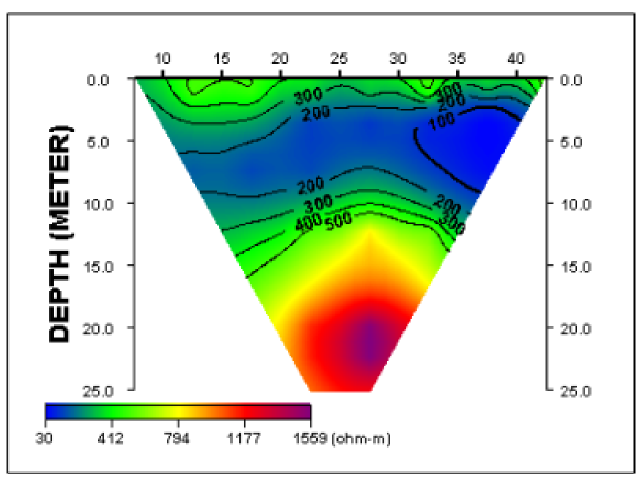

Fig. 9. 2-D subsurface resistivity image along traverse 5.

Traverses 6, 7 and 8

The resistivity section along the traverses (Fig. 10) shows resistive topsoil which composed of clayey sand/laterite with resistivity values varying from 302 – 833 ohm-m. Beneath this layer, is a pocket of conductive material forming a closure with resistivity values varying from 50 – 150 ohm-m at depth between 5 m – 10 m. This layer indicates the presence of high water retaining material due to its very low resistivity value range. The third layer with resistivity values in the range of 274 – 500 ohm-m at depth between 10 – 15 m which indicates the presence of a weathered/fractured basement material. The fresh basement layer is a resistive layer with resistivity values varying from 837 – 1510 ohm-m indicating the presence of a fresh basement rock.

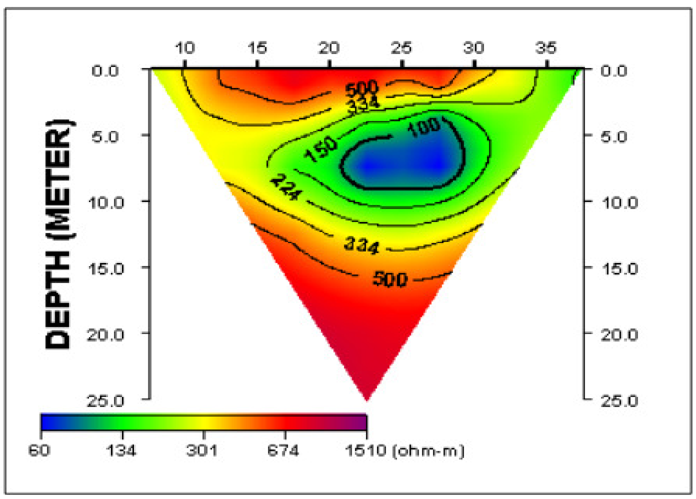

Fig. 10. 2-D subsurface resistivity image along traverses 6, 7 and 8.

Conclusions

The integrated geophysical methods served as a useful tool for post foundation study that showed the inhomogeneous subsurface geologic setting underlying the building. It has helped in the determination of the incompetent zones in the study area. The weathered layer beneath the topsoil upon which the foundation was formed displayed relatively low resistivity ranging from 42 – 151 ohm-m typical of incompetent clayey formation with thickness which varies from 1.7 m to 9.5 m. Fracture zones (F-F') identified constitute the major faulted zones underlying the building which are responsible for its instability. Structural failure related cracks on the building is due to the presence of these underlying weak, active clay at shallow depths and the occurrence of sub-surface features occupied by low resistivity weathered materials which is very unsuitable for erecting a building. Future planning for the construction of new buildings in the area should be erected on the fresh bedrock with pile foundation since the fresh bedrock lies beneath the fractured basement to ensure integrity of buildings.

This study shows that integrated geophysical investigation is useful as a relatively low cost tool to know about subsurface geological characteristics and their geoengineering properties which can be gainfully utilized in erecting civil structures in a safe and sound manner.

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References

Adewumi I. and Olorunfemi M. O. 2005. Using Geoinformatics in Construction Management. Journal of Applied Sciences, 5(4):761-767.

Dippro for windows. DipproTM Version 4.0. 2000. Processing and Interpretation software for Dipole – Dipole electrical resistivity data. KIGAM, Daejon, South Korea.

Johnson, R. B. and DeGraff, J. V. 1988. Principles of Engineering Geology: John Wiley and Sons, New York, 118-123.

Leucci, G. and De Giorgi, L. 2005. Integrated Geophysical Surveys to assess the Structural Conditions of a Karstic Cave of Archaeological Importance, Natural Hazards and Earth System Sciences. 5,17-22.

Oluwafemi, O. 2012. Electrical Resistivity Imaging Survey for Shallow Site Investigation at University of Ibadan Campus Southwestern Nigeria. ARPN Journal of Engineering and Applied Sciences, 7(2), 1-10.

Oluwafemi, O. and Ogunribido, T. H. T. 2014. Integrated Geophysical and Geotechnical Assessment of the Permanent Site of Adekunle Ajasin University, Akungba Akoko, Southwestern Nigeria. Advances in Applied Science Research, 5(2), 199-209.

Patra, H. P. and Nath, S .K. 1998. Schlumberger Geoelectric Sounding in Ground Water. Principles, Interpretation and Application. A. A. Balkema Publishers, USA, 153.

Pirttijarvi, M. 2004. KHF filt Program, A Geophysical Software for Karous-Hjelt and Fraser Filtering on Geophysical VLF (Very-Low Frequency) Data, Geophysics Division Department of Geosciences, University of Oulu, Oulu, Finland.

Rahaman, M. A. 1988. Recent Advances in the Study of Basement Complex of Nigeria. Geological Survey of Nigeria, 11–41.

Reynolds, J. M. 1997. An introduction to Applied and Environmental Geophysics, West Sussex, England: John Wiley and Sons Ltd, 796.

Sands, T. B. 2002. “Buildings Stability and Tree Growth for in Swelling London Clay-Implications for Pile Foundation Design”. Accessed 12 February 2014. Available: http://www.agu.org.

Tim, C. 2002. “House Foundation. Ask the Builder, Nationality Syndicated Newspaper Columnists”. Accessed 12 February 2014. Available: http://www.askthebuilder.com.

Tomlingson, M.J. and Boorman, R. 1999. Foundation Design and Construction. Longman Scientific and Technical, Singapore, pp.1- 125.

Vander Velpen, B. P. A. 2004. Win Resist Version 1.0 Resistivity Depth Sounding Interpretation Software. M. Sc. Research Project, ITC, Delft Netherland.

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